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ATTRACTION OF FEMALE DIGGER WASPS, *ASTATA OCCIDENTALIS* CRESSON (HYMENOPTERA: SPHECIDAE) TO THE SEX PHEROMONE OF THE STINK BUG *THYANTA PALLIDOVIRENS* (HEMIPTERA: PENTATOMIDAE)

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Abstract.—In field trials with male-produced sex pheromones of the stink bug *Thyanta pallidovirens*, the sphecid wasp *Astata occidentalis*, which preys on stink bugs, was also trapped. Only female wasps were trapped, suggesting that the bug pheromone is used by female *A. occidentalis* as a kairomone to locate prey for nest provisioning. The wasps were attracted by the main component of the stink bug pheromone, methyl (2*E*,4*Z*,6*Z*)-decatrienoate, and to blends of that compound with the minor components, the sesquiterpenes zingiberene, sesquiphellandrene, and α-curcumene.

Key words.—Insecta, *Astata occidentalis*, *Thyanta pallidovirens*, host attractant, methyl (2*E*,4Z,6Z)-decatrienoate, kairomone, pheromone.

Stink bugs (Hemiptera: Heteroptera: Pentatomidae), as their name suggests, produce copious quantities of odorous defensive secretions when disturbed. There is an increasing body of literature indicating that pentatomid species also produce volatile sex or aggregation pheromones (reviewed in McBrien and Millar 1999), albeit in lesser quantities than the defensive chemicals. These volatile signals are quite different chemically than the alcohols, aldehydes, esters, and hydrocarbons that typically constitute stink bug chemical defenses. The pheromones serve as a chemical beacon advertising the location of the emitting bug, and a variety of dipteran and hymenopteran predators and parasitoids are known to exploit these compounds as host-location kairomones (reviewed in Aldrich 1995, 1999).

Digger wasps (Hymenoptera: Sphecidae) in the subfamily Astatinae are ground-nesting, specialist predators of hemipteran nymphs and adults (Arnett 1993). Although their biology has received little study, the available host records suggest that female wasps specialize on a limited range of bug species (Evans 1957, 1996; Powell and Burdick 1960). The female wasps provision their underground nests with paralyzed bugs, usually providing each egg with several hosts for development. It has been suggested that sphecid wasps preying on stink bugs may use bug semiochemicals as host location cues (Aldrich 1995), but to date, there has been no hard evidence in support of this hypothesis. We have been investigating the sex pheromone chemistry of the stink bug *Thyanta pallidovirens* Stål for several years. Because of the considerable literature on the attraction of predators and parasitoids to heteropteran semiochemicals (review, Aldrich 1999), during field trials with reconstructed blends of the male-produced *T. pallidovirens* pheromones, we were careful to collect all insects caught in the pheromone-baited traps, not just the stink bugs that were the primary targets of the trapping experiments. We report here that traps baited with various blends of the *T. pallidovirens* pheromone components caught significant numbers of adult females of the wasp *Astata occidentalis* Cresson (Hymenoptera: Sphecidae: Astatinae).

Materials and Methods

Field Trials.—In the first trial, traps consisted of plexiglass cylinders (20 cm long × 7.5 cm O.D.) with the ends enclosed by inward-pointing cones fashioned from window screen, with a 6 mm entrance hole at the tip of the cone. Traps were placed on the ground within alfalfa, vetch, or native weeds on field borders. Pheromone baits consisted of 11 m grey rubber septa (The West Co., Lititz, Pennsylvania) impregnated with methylene chloride solutions of the pheromone chemicals. Treatments were: 1) 1 mg of methyl (*E*2,*Z*4,*Z*6)-decatrienoate, 2) methyl (*E*2,*Z*4,*Z*6)-decatrienoate + α-curcumene (2.5 mg) + zingiberene (1.92 mg) + sesquiphellandrene (0.25 mg), and 3) a solvent-treated control. Traps were replicated twice and were checked twice weekly from June 29–July 13, 1998, collecting all insects in the traps for identification. In addition, for the period June 29–July 1, 2 tube traps baited with 3 virgin male *T. pallidovirens* each were included in the experiment.

In a second trial, using live male *T. pallidovirens* as baits, traps were fashioned from 3.8 liter clear plastic screw-cap soda bottles, with the bottoms cut off and rectangular slits cut in the sides to allow good ventilation and easy entry of bugs. The bottles were suspended with the conical end down, with ~200 ml of 20% ethylene glycol solution added to catch and preserve bugs. Traps were covered with a waxed cardboard wing-trap top (Pherocon 1C, Trécé, Salinas, California). The lure consisted of a 100 ml plastic vial containing three virgin male bugs and some green beans for food, suspended inside the trap body 5 cm above the ethylene glycol trapping solution. The vial had mesh-covered cut-outs around the sides to allow diffusion of semiochemicals produced by the male bugs. A pair of traps were hung from two pistachio trees separated by ~40 m in Madera County, California, pistachio orchards, and traps were retrieved 7–10 d later. The experiment was repeated three times.

Two further trials were conducted in tomato fields near Modesto, Stanislaus County, California, using commercial stink bug traps (Sierra Ag., Fresno, California) consisting of 4 liter clear plastic screw-cap jars with two inward-pointing screen cones on opposite sides of each jar. Traps were placed on the ground between beds. In the first of these trials, traps were baited with 1 ml snap-cap polyethylene centrifuge tubes loaded with neat *T. pallidovirens* pheromone. In the second of these trials, traps were baited with grey rubber septa impregnated with synthesized pheromones of either *T. pallidovirens* or the Consperse stink bug, *Euschistus conspersus* Uhler. In both trials, trap catches were tabulated weekly.

Voucher specimens of *A. occidentalis* were deposited at the University of California Riverside Entomology Museum.

Chemicals.—Methyl (2*E*,4*Z*,6*Z*)-decatrienoate and racemic α-curcumene were synthesized as previously described by Millar (1997) and Hall et al. (1975), respectively. Zingiberene was isolated from ginger oil (Spectrum Chemical Co., Gardena CA) (Millar 1998). Sesquiphellandrene was isolated from ginger oil by

Table 1. Total numbers of female *Astata occidentalis* caught in traps baited with synthetic sex pheromone of male *Thyanta pallidovirens,* or live male *T. pallidovirens.* Traps were replicated twice, and were in place from June 29–July 13, 1998, except for traps with live males, which were in place from June 29–July 1, 1998.

Lure*	Female wasps caught
Ester + sesquiterpenes	40
Ester alone	29
Blank	0
3 live male bugs	4

* Lure contents and doses are listed in Materials and Methods.

flash chromatography on silica gel (230–400 mesh, activated by drying at ~125° C overnight), eluting with hexanes. Consperse stink bug pheromone (methyl *E*2,*Z*4-decadienoate) was purchased from Bedoukian Research (Danbury, CT).

Results

A total of 69 adult female *A. occidentalis* were captured in tube traps baited with experimental *T. pallidovirens* male sex pheromone blend (Table 1). No *T. pallidovirens* of either sex were caught in any of the traps containing wasps, clearly indicating that the wasps had been attracted by the synthesized pheromones. Furthermore, no wasps were captured in any control traps, nor were any male wasps captured. Both methyl (*E*2,*Z*4,*Z*6)-decatrienoate as a single component, or this ester as part of the 4-component mixture produced by sexually mature male *T. pallidovirens* (J. G. Millar, unpublished data) attracted female wasps, suggesting that the ester alone is primarily responsible for the attraction (Table 1). During a 3-day period of this trial, 2 traps baited with live male *T. pallidovirens* also trapped two female wasps each.

In a second trial, using traps in pistachio orchards baited with live male bugs, 2 traps baited with live male *T. pallidovirens* caught totals of 2 and 12 female *A. occidentalis* wasps respectively. However, blank controls were not included in this trial, whose principal purpose was the testing of a new stink bug trap design.

In a third field test conducted in tomato fields using synthetic *T. pallidovirens* pheromone dispensed from polyethylene vials, of the 86 female *A. occidentalis* caught in traps baited with the ester alone or the ester in combination with the sesquiterpenes, all but two of the wasps were caught in traps that had caught no bugs. These results confirmed that the wasps were attracted to the synthetically reconstructed pheromone of their stink bug prey.

Female wasps were attracted only to traps baited with *T. pallidovirens* pheromone. In a trial in which pheromone baits for *T. pallidovirens* and Consperse stink bug, *Euschistus conspersus,* were tested simultaneously, a total of 28 *A. occidentalis* females were caught in traps baited with *T. pallidovirens* pheromone blends, whereas only a single wasp was caught in traps baited with *E. conspersus* pheromone.

Discussion

There is an increasing body of literature indicating that predators and parasitoids can eavesdrop on their hosts' pheromones, using these volatile chemicals as kairomones to locate their prey (reviewed in Haynes and Yeargan 1999). For example, numerous predatory beetles and flies locate their bark beetle prey using the beetles' aggregation pheromones (reviewed in Aldrich 1999), and the predatory bug *Elatophilus hebraicus* is attracted to the female sex pheromone of its prey, the scale *Matsucoccus josephi* (Mendel et al. 1995). Similarly, foraging yellowjacket wasps, *Vespula germanica*, locate leks of male Mediterranean fruit flies using the male-produced pheromone, and there was some evidence to suggest that the wasps learned to associate the odor of the pheromone with their prey (Hendrichs et al. 1994, 1998).

T. pallidovirens pheromone consists of an ester component with at least one of the three male-produced sesquiterpene hydrocarbons; the ester alone or the sesquiterpenes alone are not attractive to female bugs (J. G. Millar, unpublished data). *A. occidentalis* females were attracted to the *T. pallidovirens* ester as a single component, as well as to blends of the ester with other components. While suggesting that the ester component alone provides a unique and unambiguous signal enabling the wasp to find its specialized prey, it does not explain why *T. pallidovirens* requires a blend of at least two components for attraction. One possible explanation might be that the ester compound is used as a pheromone component by several *Thyanta* species, all of which may be suitable prey for the wasp, and that the species specificity of the pheromone signal is provided by the other components. Conversely, if the wasp preys upon several *Thyanta* species that share the same major pheromone component, it would be advantageous to respond to the single component alone, regardless of what other components were present.

The major component of the *E. conspersus* pheromone, methyl *E*2,*Z*4-decadienoate (Aldrich et al. 1991), differs from the *T. pallidovirens* ester by only a single double bond. Nevertheless, the wasps appeared to be able to distinguish it from the *T. pallidovirens* pheromone because in a field trial in which the pheromones of both species were tested simultaneously, 28 of the 29 wasps caught were captured in traps containing *T. pallidovirens* pheromone. Trap catches in all trials were also completely sex specific, with only female wasps being caught, as would be expected if female wasps were using their hosts' pheromone as a kairomone for finding nest provisions. Male wasps do not have this requirement, and would not be expected to be attracted.

During the experiments described, few *T. pallidovirens* of either sex were caught in pheromone-baited tube traps, for several possible reasons. First, the trap design appears to be unsuitable for stink bugs. Significant numbers of female *T. pallidovirens* were caught in subsequent experiments in tomato fields with the same lures but a different trap design (McBrien, Millar, and Cullen, manuscript in prep.). Second, the pheromone appears to be a relatively weak attractant for female bugs, as has been reported with the pheromones of several other phytophagous stink bug species (reviewed in Millar and McBrien 1999). Third, there is mounting evidence that over shorter distances, male and female stink bugs locate each other through substrate-borne vibrational signals (e.g., Ota and Cokl 1991, Cokl et al. 2001). These signals obviously are not provided by a pheromone-baited trap. Thus, female bugs may indeed be attracted to the vicinity of a pheromone source, but may have difficulty locating the pheromone source because it does not produce the vibrational signals required for short-range guidance.

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